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An Analysis of Horizontal Dispersion Due to the Drift Current with an Ekman Layer

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An analytical method for describing horizontal matter dispersion in shear currents is presented using a tensor expression from the point of view that matter dispersion due to the shear effect should be one of the principal mixing dilution processes. Although the behavior of horizontal dispersion is considerably more complicated than common longitudinal dispersion, the present study elucidates the vertical structure of dispersion and the dispersing process from the initial to the stationary stage, besides the usual depth-averaged dispersion coefficient at the stationary stage. As one of the typical applications of horizontal dispersion, dispersion due to the pure drift current with an Ekman layer is examined theoretically using the present method. This examination reveals that the displacement of the centroid and the major axis of dispersion are twisted in the vertical direction more than the direction of the current vector forming the Ekman spiral; that the variance increases in proportion to the third power of the elapsed time; and that the dispersion coefficient at the stationary stage remains constant, independent of the depth normalized by an Ekman layer thickness. Such dependence of the dispersion coefficient in the steady current is shown to be different from that in the oscillatory current, which is inversely proportional to the depth normalized by a Stokes layer thickness. This is considered to be induced by the difference of the vertical profiles of the first order moment in both currents, that is, the shear region of the first order moment is restricted around the floor by the alternation of the current shear in the oscillatory current while it is diffused in the whole depth in the steady current.

Keywords:
- Horizontal dispersion,
- dispersion coefficient tensor,
- the drift current,
- an Ekman layer.

1. Introduction

Matter dispersion due to the shear effect of current has been usually analyzed as longitudinal dispersion in a one-dimensional direction (Taylor 1953, 1954; Elder 1959; Bowden 1965, etc.). Although such longitudinal dispersion ought to be basic and significant for understanding the nature of matter dispersion, currents in the real ocean generally have a two-dimensional variation, such as the Ekman spiral in steady currents and the tidal current ellipse in oscillatory currents. Matter dispersion due to currents with vertical variations, such that the orientations are different at different depths, is considered to behave more intricately in a three-dimensional basin than the usual longitudinal dispersion where matter is dispersed in only one direction, and it needs to be analyzed using a tensor expression in a horizontal plane with two dimensions. The author has already shown that matter dispersion due to the shear effect was an important mixing dilution process similar to molecular and turbulent diffusion in the mass transport process (Yasuda 1982, 1984, 1988, 1989). Continuing from these works, this study will present an analytical method of horizontal dispersion and elucidate the nature of matter dispersion due to a drift current with an Ekman layer as a typical example of horizontal dispersion.

Such horizontal dispersion has already been analyzed by some researchers. Csanady (1966, 1969) paid attention to transverse dispersion in an Ekman layer, and Fischer (1978) presented the tensor of the horizontal dispersion coefficient at the stationary stage in an idealized current. Further, Hamrick (1986) evaluated the horizontal dispersion coefficient tensor in tidal and drift currents, and Smith (1990) analyzed horizontal dispersion of miscible fluid in machinery. Smith (1996) advanced his analysis to the model of coastal waters with the rotation effect. Reports by Hamrick and Smith were fruitful, making the greatest use of the highly mathematical technique to obtain the solutions of horizontal dispersion vertically averaged at the stationary stage. As previously described (Yasuda 1988, 1989), the characteristic

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